

SPACE EXPLORATION — WHY AND HOW

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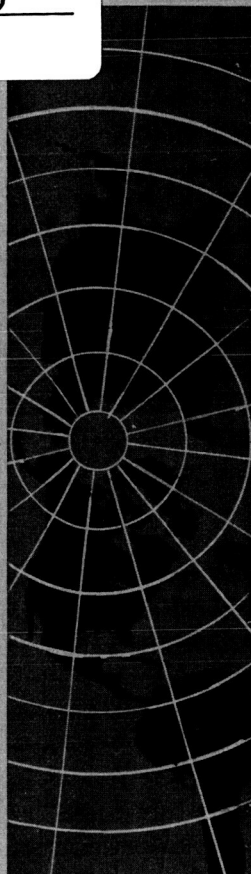
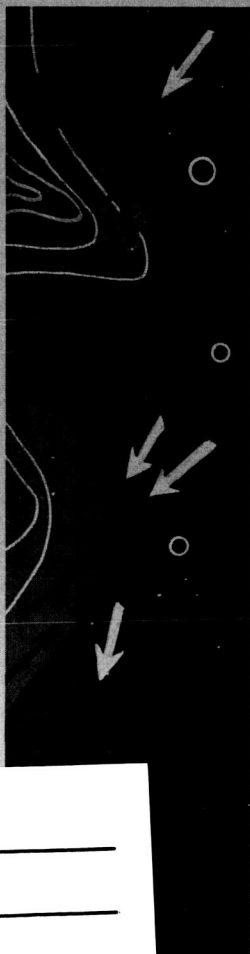
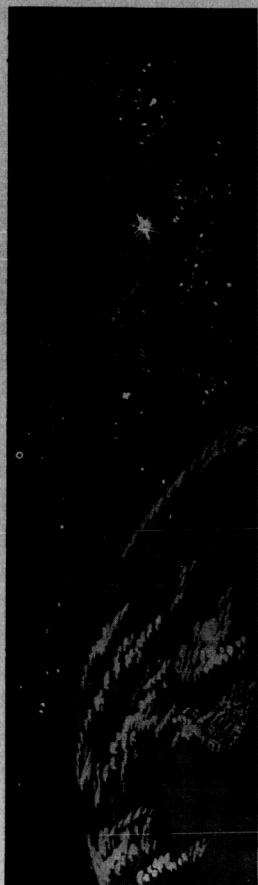
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By EDGAR M. CORTRIGHT
Deputy Associate Administrator
for Space Science and Applications

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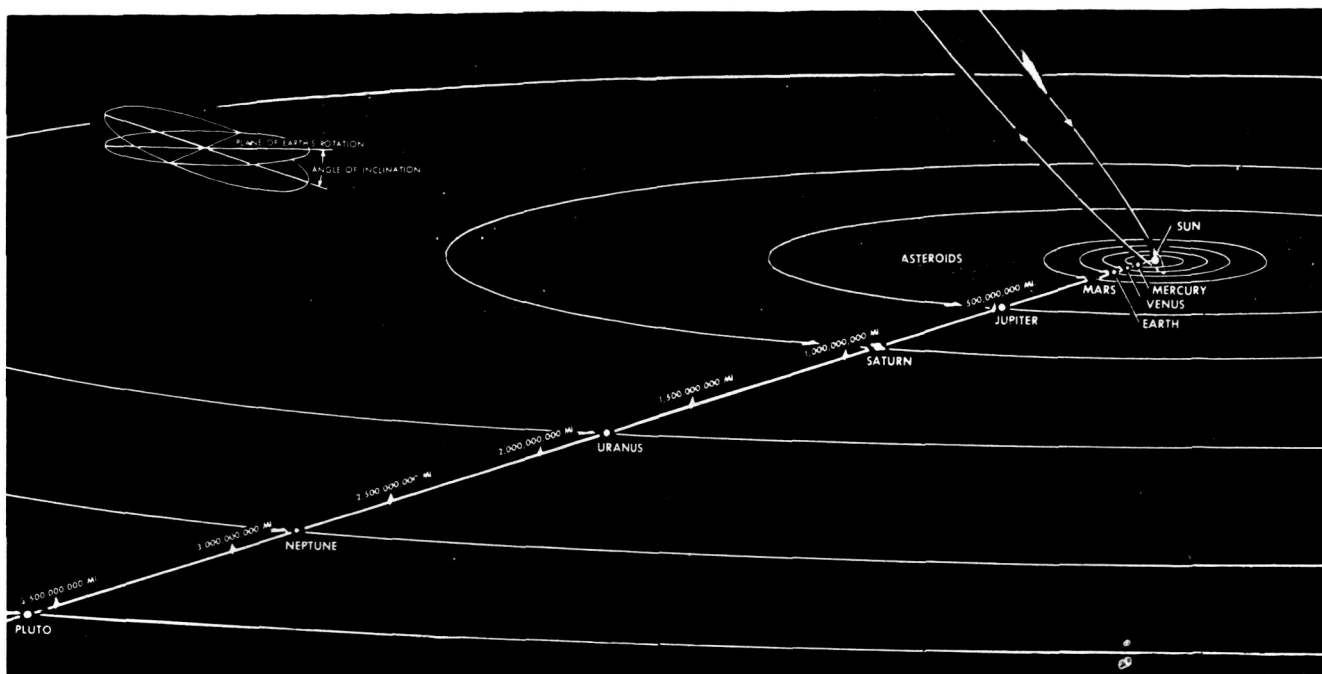
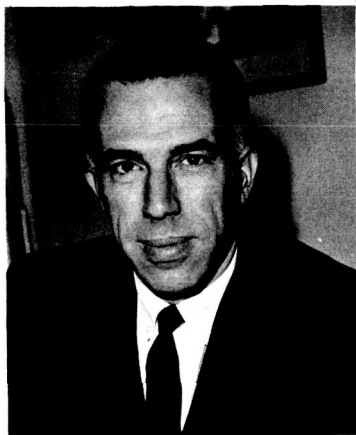


FIGURE 1. WHAT ARE WE EXPLORING?

SPACE EXPLORATION - WHY AND HOW



By EDGAR M. CORTRIGHT
Deputy Associate Administrator
for Space Science and Applications

Edgar M. Cortright was appointed Deputy Associate Administrator for Space Science and Applications on November 1, 1963. In this position, he shares responsibility with Dr. Homer Newell, Associate Administrator for Space Science and Applications, in planning and directing NASA's programs for the unmanned scientific exploration and utilization of space. These programs include the lunar and planetary probes, the geophysical and astronomical satellites and probes, bio-sciences, applications satellites, and the development and use of light and medium launch vehicles through the Atlas-Centaur class.

The material in this booklet is substantially the text of an address delivered before the Norwegian Geographical Society on September 27, 1964.

Each generation faces the perennial crisis of running out of new frontiers to explore. Space exploration is the most recent of these "last" frontiers. There is nothing esoteric about it. It is exploration in the truest and most romantic sense. It requires all of the classical ingredients: men, machines, curiosity, and determination.

For those who would worry about last frontiers, the vastness of space is not likely to yield up all its secrets in the foreseeable future—if ever. This is obvious when one considers the awesome setting for space exploration. (Figure 1)

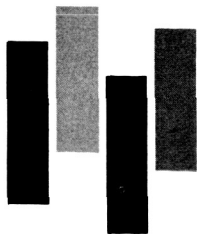
Within the 11 billion trillion mile range of our largest telescopes, there are some trillion galaxies containing several billion stars each. What lies beyond one can only surmise. The great spiral galaxy of Andromeda shown here is similar to our own galaxy, the Milky Way. Our sun is but one of the billions of stars within the Milky Way. The nearest star to our sun is over 25 trillion miles away.

A major goal of exploration, including earth exploration, has been to understand how our solar system was formed. Since the solar system contains the sun, 9 planets, 31 moons, 30,000 asteroids or minor planets, and thousands of comets, we cannot hope to reach many of these celestial objects in the near future. We are thus concentrating on the earth, its moon, Mars, Venus, and the sun. Only our orbiting telescopes will peer beyond into the starry, timeless, endless universe with its awesome lessons in humility.

SUMMARY

The question is often asked, "Why explore space when much of our earth remains unexplored?" In this booklet, I hope to provide some of the answers. Most of these answers stem from the fact that space exploration is intimately related to earth exploration. In reaching out into space and to other worlds, we are providing a unique look at our own.

The main sections of this paper are:



SPACE AROUND THE EARTH

**ATMOSPHERIC CIRCULATION AND
THE WEATHER**

THE EARTH

THE MOON AND THE PLANETS

SPACE AROUND THE EARTH



Earth exploration has always been limited by time and distance. Space flight constitutes a gigantic step forward in overcoming these limitations. Man can now make direct observations of the earth and its environs on a global scale in a matter of hours, if not minutes.

Some of the important characteristics of our earth which are now being studied with instrumented satellites are illustrated in Figure 2. They include the earth's shape, its magnetic field, the great radiation belts, auroras, the ionosphere, and the atmosphere.

Most of these earthly phenomena are strongly influenced by the radiations from the sun. Hence, any comprehensive study of the earth and its environment must include a study of the sun.

Let us first examine the earth's magnetic field or magnetosphere, and the trapped radiation belts within it. In this figure, a cross section of the belts is shown as they were envisioned several years ago. These belts consist of electrons and protons spiraling about the earth's magnetic lines of force. Some are highly energetic and can damage both men and equipment. The escape and replenishment of these trapped particles from the belts is not fully understood.

Figure 3 illustrates our current understanding of the shape of the magnetosphere, in which lie the radiation belts. The flight of Mariner II to Venus in 1962 proved the hypothesis of a solar wind, that is, a steady outward streaming of electrons and protons from the sun. These particles are thought to flow around the moon and the earth much like water around boulders. In the case of the moon, which has little or no magnetic field according to

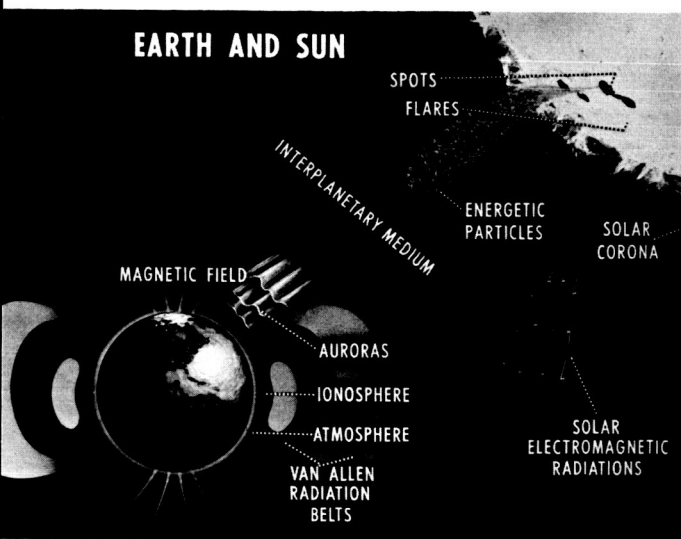


FIGURE 2

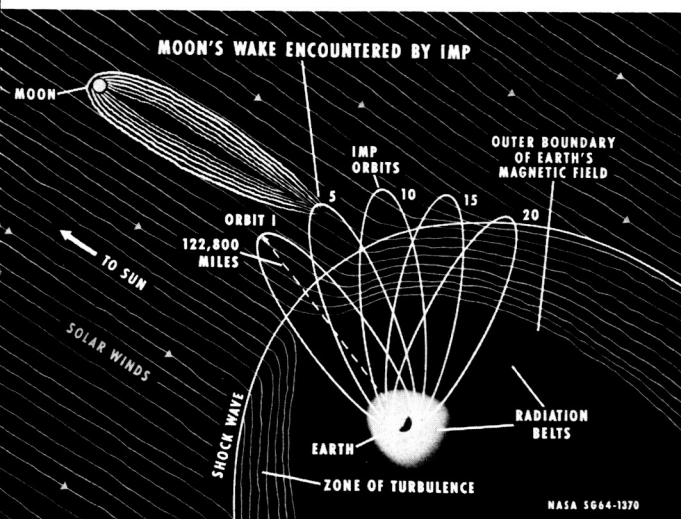


FIGURE 3

Soviet measurements, the surface deflects the flow. With the earth, however, the flow is deflected by the earth's magnetic field. Most of the particles don't get much closer than about 37,000 miles on the sunlit side. The flow distorts the earth's magnetic field, causing a wake-like shape on the side of the earth away from the sun. Where the fast moving solar wind (180 to 360 miles/sec) first encounters the earth's field, there appears to be a shock wave much like those caused by supersonic aircraft.

One of the satellites with which we are studying these phenomena is Explorer XVIII, also called Interplanetary Monitoring Platform or IMP. Its apogee is about 115,800 miles and is high enough for the IMP to encounter and detect the moon's wake, which we think it has. As the orbit precesses, it sweeps out different portions of the earth's magnetosphere and is giving us a much better picture of its true shape and nature. Spacecraft designed to orbit the moon will provide similar coverage of this body.

What is probably the world's most advanced satellite for investigating the space around the earth is the Orbiting Geophysical Observatory or OGO, shown in Figure 4. This 1000 pound spacecraft is designed to carry over 20 experiments in orbits ranging out to 78,000 miles. It is designed to be fully stabilized, using a combination of reaction wheels and gas jets. OGO can thus simultaneously point selected equipment toward and away from the earth, toward and away from the sun, and in the direction of flight. On the first flight, the OGO failed to extend several of its many folding booms. As an indirect result, too much of its stabilizing gas was used in the first day, so we were forced to allow

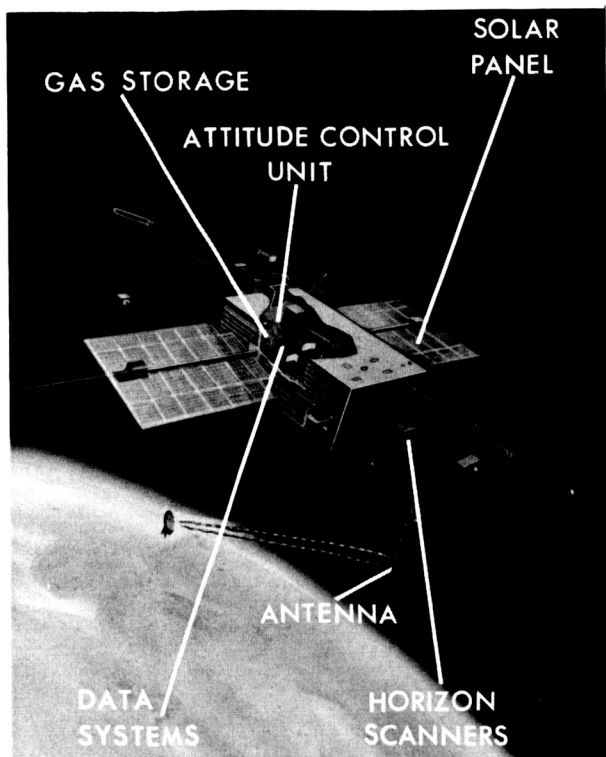


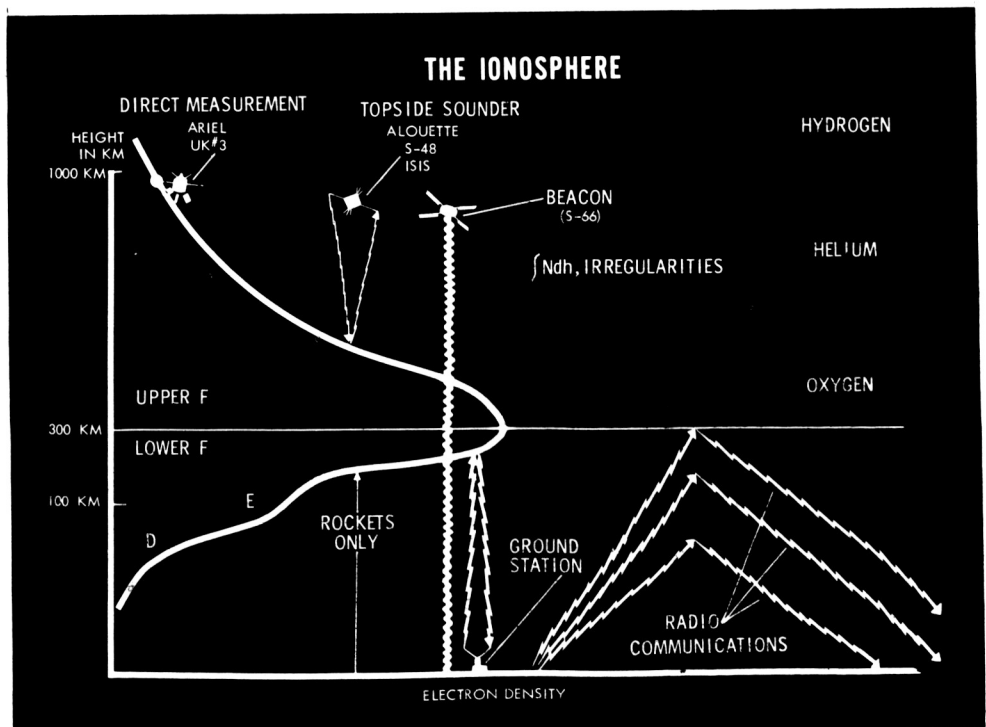
FIGURE 4. ORBITING GEOPHYSICAL OBSERVATORY. Gross Weight—1,000 lbs • Instrument Weight—150 lbs • Investigations—20/Spacecraft • Power—560 watts • Stabilization—Active 3 Axis • Design Life—one year • Launch Vehicles—Atlas-Agena, TAT-Agena • Orbits—highly elliptical inclined orbit, near circular polar orbit plan—first flight—1964.

the spacecraft to remain spinning. Most of the experiments are yielding good data, however. Several more OGO's are being built.

Another important phenomenon of the space around the earth is the ionosphere. Figure 5. The ionosphere consists of a layer of ions and free electrons in the outer fringes of the earth's atmosphere. It is believed, to be generated primarily by the ionizing effects of solar ultraviolet radiation. We depend on the ionosphere to reflect radio signals from one spot on the earth's surface to another as shown in the figure. Because of its changeable nature, the ionosphere is not an entirely dependable link in long range communication, particularly at high latitudes. For this reason, and for purely scientific ones, the ionosphere has been the subject of intensive research.

Before earth satellites, we were able to measure the variation of the concentration of electrons with altitude by means of reflected radio signals from the ground. This only works for the lower half of the ionosphere in the vicinity of the transmitting station. Sounding rockets provided some measurements in the upper ionosphere but it was impossible to gain

FIGURE 5



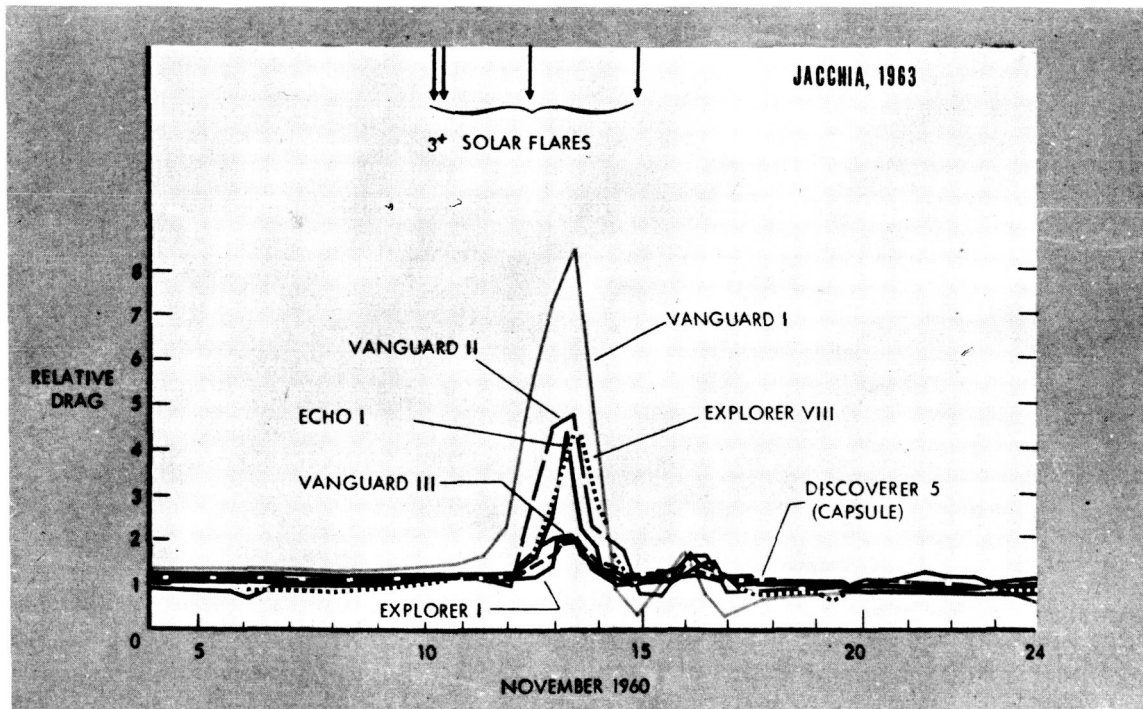
a full understanding of the ionosphere by these techniques. Now earth satellites are used in three ways. The Alouette, a Canadian-built and U. S.-launched satellite, and the recent Explorer XX, measure their own reflected radio signals to determine the upper profile of the ionosphere over the entire world. The British-built and U. S.-launched Ariel makes direct measurements like the sounding rocket, but with world-wide coverage. A new Explorer satellite, soon to be launched, will be monitored by about 150 scientists at 80 stations in 32 countries to determine the total electron count in their areas and thus establish world-wide variations.

Another element of the space around the earth is the upper atmosphere. Earth satellites are proving to be an invaluable tool in the study of the

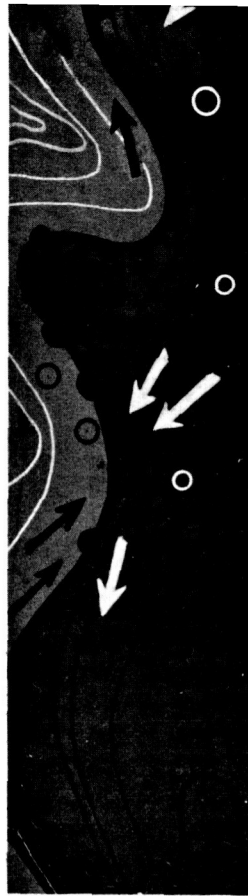
earth's upper atmosphere above 120 miles where sounding rockets can only infrequently and locally sample. For example, Figure 6 illustrates the effect of solar radiation on the density of those rarefied gases. Simply stated, the figure shows how the drag of seven tracked satellites increased immediately following the occurrence of several large solar flares. This results from an expansion upward of the radiation warmed atmosphere below the satellites.

Tracking of Echo I led Marcel Nicolet of Belgium to suggest the existence of a layer of helium between the oxygen/nitrogen inner atmosphere and the hydrogen outer atmosphere. We later confirmed this with a special satellite, Explorer XVII which made direct spectrometric analyses and telemetered the results to earth.

FIGURE 6. SOLAR EFFECTS ON EARTH'S ATMOSPHERE.



ATMOSPHERIC CIRCULATION AND WEATHER



We are all interested in the weather. (Figure 7) It affects our comfort, health, safety, and economic welfare. But what we think of in very personal terms as a local phenomenon is in reality but one manifestation of a gigantic pattern of circulating air over the entire globe. This global circulation can be likened to the movement of a huge heat engine powered by the sun and the rotation of the earth.

The earth satellite is now providing the meteorologist what he has always wanted, a chance to look at the weather on a global scale. The sparsely covered regions of the earth such as the poles, the oceans, and much of the southern hemisphere can now be completely observed several times each day. Because satellites cannot yet measure pressure, temperature, and wind velocities at various altitudes below them, they are as yet only additional tools to help the meteorologist. But instruments are being developed to increase the utility of the meteorological satellite. In addition, they are being developed to collect and report measurements from unattended meteorological stations on the land and sea, and in the air.

In the meantime, cloud pictures are providing a glorious representation of the earth's atmosphere in action. Let's look at a few examples of meteorological photography. This classic montage of cloud photographs was made from TIROS television pictures in May 1960. The coverage stretches from the coast of Japan to the Great Lakes of the United States. In the lower half of the figure is shown the corresponding conventional weather map of isobars with highs, lows, and fronts. An artist has rectified the upper montage and superimposed it upon the map. The correspondence is impressive. Note the cyclonic cloud patterns at the three lows, and the cloud lines along the temperature fronts. Today we can prepare such cloud pictures for the entire world on a daily basis using our new TIROS and Nimbus satellites.

Nine TIROS and one Nimbus satellites have been launched to date. All were highly successful. They have provided hundreds of thousands of cloud photographs, detected dozens of hurricanes and typhoons, provided thousands of weather alerts and

FIGURE 7. STORMS AND FRONTS—A FAMILY OF WEATHER SYSTEMS. MOSAIC OF TIROS PHOTOGRAPHS. WEATHER MAP, MAY 20, 1960, WITH TIROS CLOUD DATA.

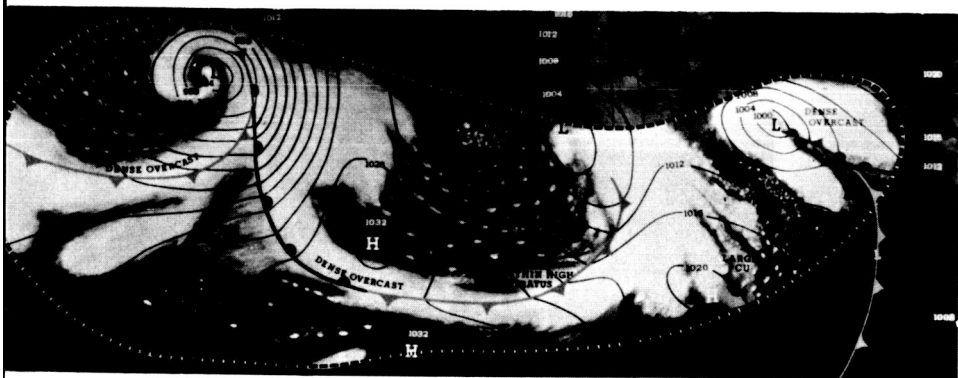


FIGURE 8. LIFE CYCLE OF A CYCLONE.



FIGURE 9. LIMITATION OF SATELLITE RADAR FOR MEASURING PRECIPITATION.



Instantaneous View.
3 hour Integrated (Superimposed on Tiros picture).



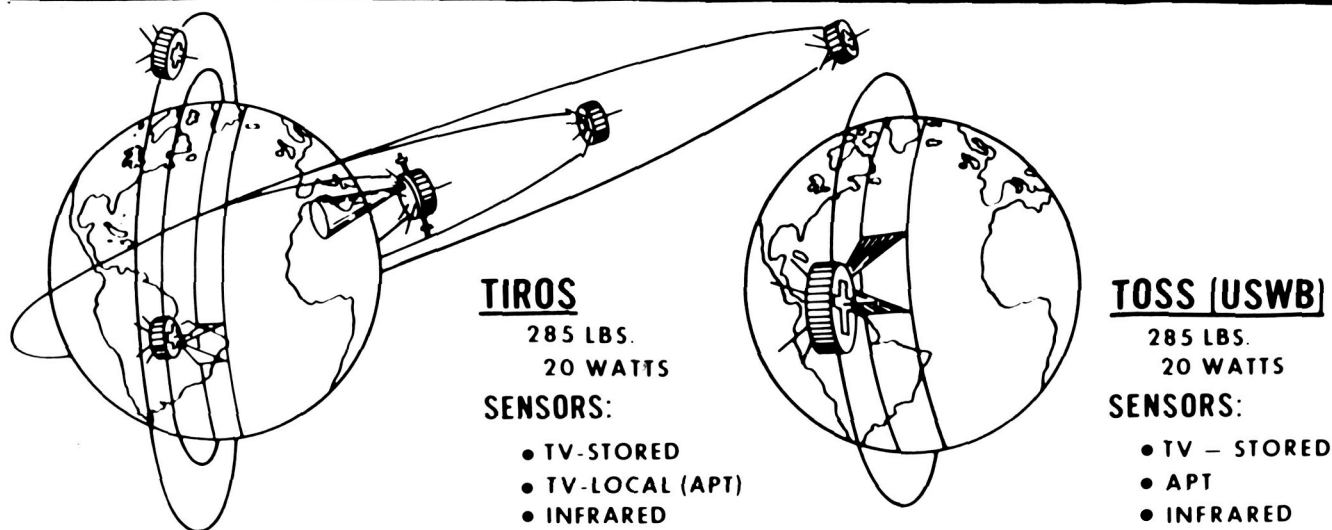


FIGURE 10. METEOROLOGICAL SATELLITES.

warnings to all regions of the world, and have been used operationally by airlines on transoceanic flights.

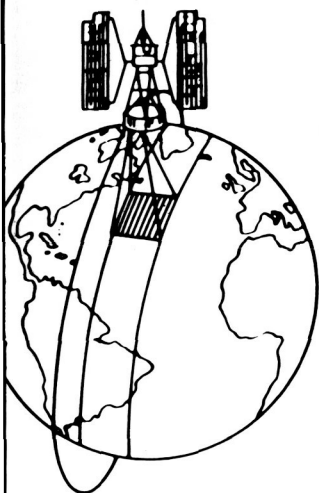
These meteorological satellites have also provided a wealth of valuable research information which will improve their effectiveness in years to come. Figure 8 illustrates how TIROS photographs of several hurricanes in various stages of development can be related to the theories of Bjerknes and Solberg, two Norwegian meteorologists. From left to right and top to bottom, the birth, life, and death phases of a hurricane are clearly shown. Only by relating cloud photographs to other measured atmospheric phenomena can cloud photography reach its full potential.

Because of the direct importance of rainfall on the comfort and welfare of the people of the world, and its indirect effect on atmospheric circulation, we have been interested in the possibility of measuring global rainfall distribution with satellite radar. Figure 9 shows the result of an early experiment. Rainfall over several midwestern states in the United States, as determined by ground-based radar, has been superimposed on a cloud photograph obtained with a TIROS flying overhead. The outlines of the states are shown, with Iowa located in the center. The dark spots buried within the cloud patterns in the left hand picture are areas where it was raining at the time of the picture. This then indicates the instantaneous view of rainfall that satellite radar might have given. The right hand picture shows

the total rainfall pattern over a 3-hour period, which is much larger. Clearly, the fast moving satellite could not have given a true picture of the total rainfall. Because of considerations such as this, we are looking with increased interest at weather satellites in the synchronous orbit at 36,000 kilometers above the equator. Such satellites remain overhead and could watch a storm develop from beginning to end.

The evolution of meteorological satellites is illustrated in Figure 10. The first 8 TIROS satellites were spin-stabilized like a gyroscope, and the cameras, which pointed along the spin axis, could only see the earth during a portion of each orbit. To overcome this limitation, we learned to turn the spin axis in flight so that the wheel-shaped TIROS appears to roll along its orbit. By pointing the cameras out the side and placing the satellite in a polar orbit, world-wide coverage can be obtained. The first such satellite TIROS IX, was launched January 22, 1965. The United States Weather Bureau has elected to use this type satellite in its first operational system.

The Nimbus, the most advanced weather satellite ever constructed, was launched into a polar orbit in August, 1964. This satellite, is fully stabilized so as to maintain its sensors pointing at the earth and its solar panels at the sun. By selecting the orbit with the proper inclination (80° retrograde) the Nimbus always passes overhead at noon and midnight.



NIMBUS

835 LBS.
200 WATTS

SENSORS:

- ADV. VIDICON CAMERAS
- HIGH RES. INFRARED
- APT
- MEDIUM RES. INFRARED
- REDUNDANT AVC



**FIGURE 12. PORTIONS OF NORWAY, SWEDEN AND DENMARK—TIROS V—
FEBRUARY 18, 1963**

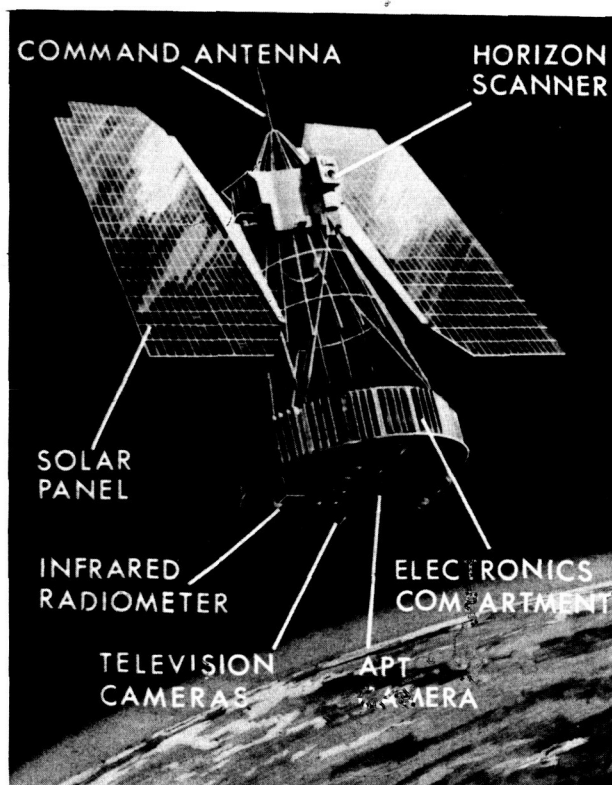


FIGURE 11. NIMBUS. Gross Weight—835 lbs. • Sensor Weight—150 lbs • PEAK POWER—470 watts • Stabilization—Active 3 Axis • Design Life—six months to one year • Launch Vehicle—Thor-Agena B • Orbit—Apogee-574 mi., Perigee-253 mi., Period-98.2 Min., Inclination-98° • First Flight—August 28, 1964.

The Nimbus is further illustrated in Figure 11. Because of its high power, a variety of advanced instruments can be carried. The primary photographic system is an array of three high resolution television cameras for world-wide daylight cloud coverage at a resolution of about $3\frac{1}{2}$ miles. The Nimbus also carries an infrared camera system for global night-time cloud coverage at a resolution of about 5 miles. It further carries an Automatic Picture Transmission system which continuously broadcasts about 1080 by 1080 mile pictures of the clouds beneath it to the countries beneath it. These pictures are also of high quality, having a resolution of .7 mile or twice the resolution of TIROS pictures. Receivers can be homemade, or purchased at nominal cost. About fifty such receiving stations are already in operation all over the world. Ten of these are owned and operated by participating nations. The APT station in Copenhagen, for example, can receive each day from the Nimbus a number of pictures much like that shown in Figure 12, but with many times the area coverage. (This particular picture was taken in 1963 by TIROS and is not an actual APT transmission.)

Three striking examples of Nimbus photography are shown in Figures 13, 14 and 15.

Figure 13 shows a 1020 x 4080 mile strip extending from Hudson Bay, Canada, to Venezuela, South

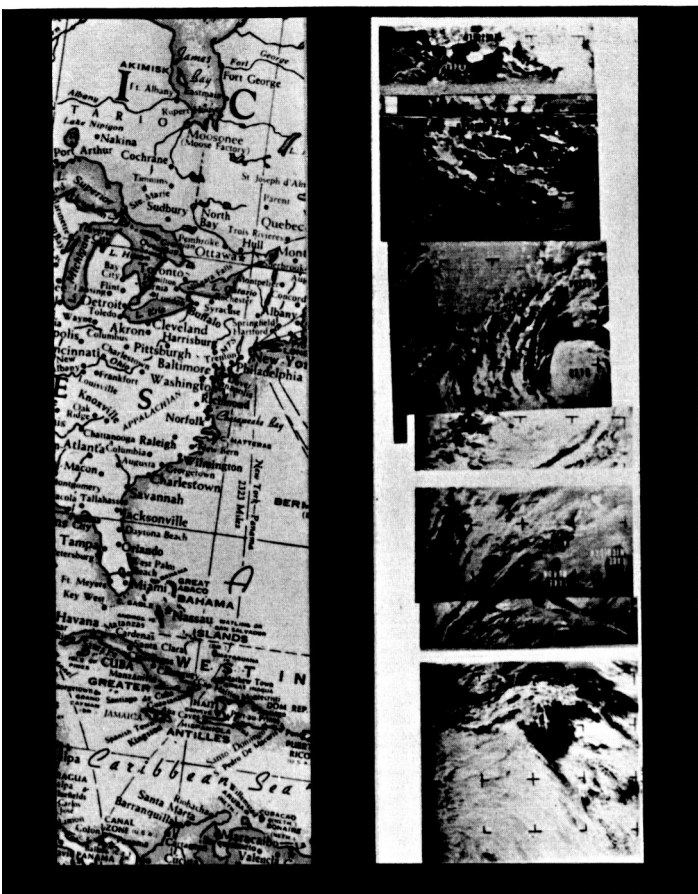


FIGURE 13. NIMBUS DAYLIGHT CLOUD PHOTOGRAPHY—APT's.

America. From top to bottom, the following can be seen: Canada and the Hudson Bay were covered with clouds. The Great Lakes of the United States were free of clouds and show clearly. The East coast of the United States from Maine to Florida was blanketed with clouds, most of which were associated with hurricane Cleo. Cleo is shown located directly over northeast Florida. Southern Florida was relatively clear. Following the figure on down, one sees the islands of Cuba, Jamaica, Haiti, and the Dominican Republic, and Puerto Rico. At the bottom of the picture, the Gulf of Venezuela is seen between the northernmost projections of Colombia and Venezuela.

This particular strip was assembled from APT photographs, taken on August 31. All of the pic-

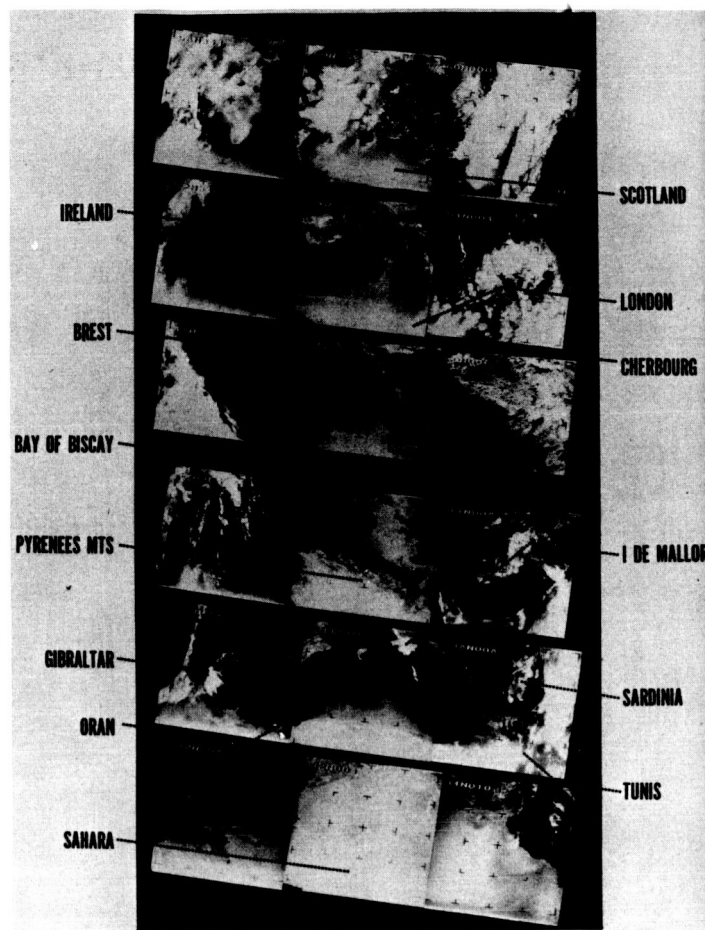


FIGURE 14. NIMBUS—AVCS PICTURES.

tures were obtained on the same orbit by a single receiving station near Washington, D.C. This illustrates that APT coverage actually extends for several thousand miles in all directions from the ground station.

Figure 14 shows a partial mosaic of Europe obtained with the three camera system on a single orbital pass. The British Isles are visible at the top with clouds over northern Ireland and haze over Scotland and southern England. France is relatively cloud free, but cumulus fields obscure the low countries and western Germany. The snow covered Pyrenees are visible with cloud fields to the south. Most of Spain is cloudless, however. Gibraltar stands out clearly, as do the Balearic Islands, Cor-

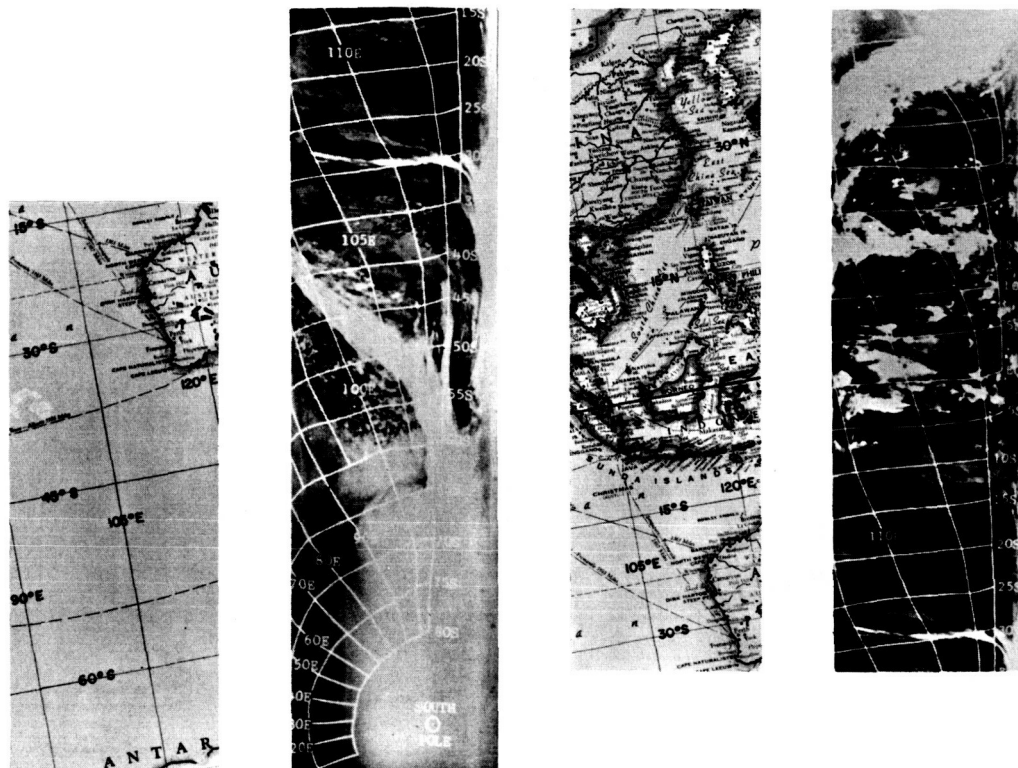


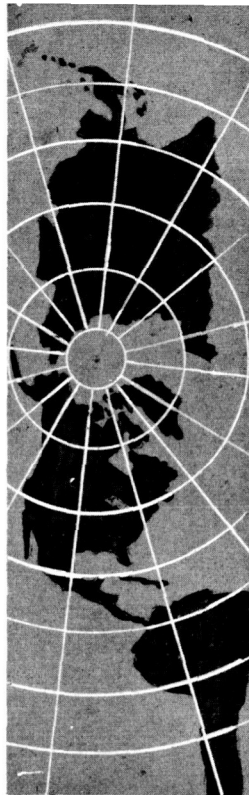
FIGURE 15. NIMBUS NIGHT CLOUD PHOTOGRAPHY—HRIR

sica, and Sardinia. The cloudless Sahara desert is bright enough under the noonday sun to appear cloud covered.

Figure 15 shows another exciting strip photograph taken at night with the infra-red camera. This camera does not take individual frames, but continuously records the scene passing beneath the satellite. The way the system works is to scan the earth with a reflecting telescope that sees only a small spot at any instant. The infrared radiation intensity from this spot is recorded on magnetic tape. In reconstructing the picture on the ground, cold sources are printed white and warm sources black, with various shades of gray in between. Thus, high altitude clouds are shown very white and low altitude

clouds less white. The snow-covered poles are white even without clouds. Land masses can be distinguished from surrounding water because of their temperature differences. This camera also works in daylight but with less contrast. From bottom to top, one can see the south polar cap with interesting cloud fields extending northward to southern Australia. The west coast of Australia is clearly seen from 30° to 20° south latitude. Shark Bay and Exmouth Gulf are the key landmarks. North of Australia, Java lies under clouds. Borneo and Sarawak, however, can be seen straddling the equator, partially covered with high clouds. The picture extends north to Manchuria, but the coastlines are indistinguishable.

THE EARTH



Seeing these pictures leads naturally to the question of whether one can improve on our knowledge of both the shape of the earth and the location of its land masses by use of satellites. The answer is yes. To illustrate the techniques, I will use a figure depicting various communications satellites launched by the United States. Figure 16.

The Echo passive communication satellites, which you have all seen, are giant balloons which, when illuminated by the sun, are visible to the naked eye. They are normally used to reflect radio signals for long range communications. By simultaneously viewing these balloons from various locations, simple triangulation can be used to locate the viewing points with great precision.

In addition to determining the precise location of land masses, satellites improve our knowledge of the shape of the earth's geoid, which is the "effective" shape of the earth. This knowledge comes from precise tracking of satellites, such as those shown here, and analysis of the changes in their orbits due to the irregularities in the earth's mass. One of the first results was the determination that the earth was very slightly pear-shaped. Later measurements have established irregularities in the shape of the equatorial geoid—which is not circular but is out of round by about 197 feet. One of the most precise determinations of this has come from the SYNCOM communications satellite, which is designed to remain overhead in a synchronous orbit. Actually, it drifts slowly due to the equatorial irregularities and must occasionally be repositioned.

Figure 17 shows the results of one geodetic analysis of satellite orbits. A depression or deficiency of mass is shown in the Indian Ocean, and an elevation or excess is shown in the western Pacific. Interestingly, these anomalies can be related to anomalies in the flow of heat from the earth's interior. In turn, these may relate to the local rising of extra hot and hence relatively lighter molten material in the earth's core. And in this manner, our continuing web of data gathered from space sharpens our knowledge of the earth.

What place has man in this array of scientific exploration? So far, most of the exploration has

COMMUNICATION SATELLITES

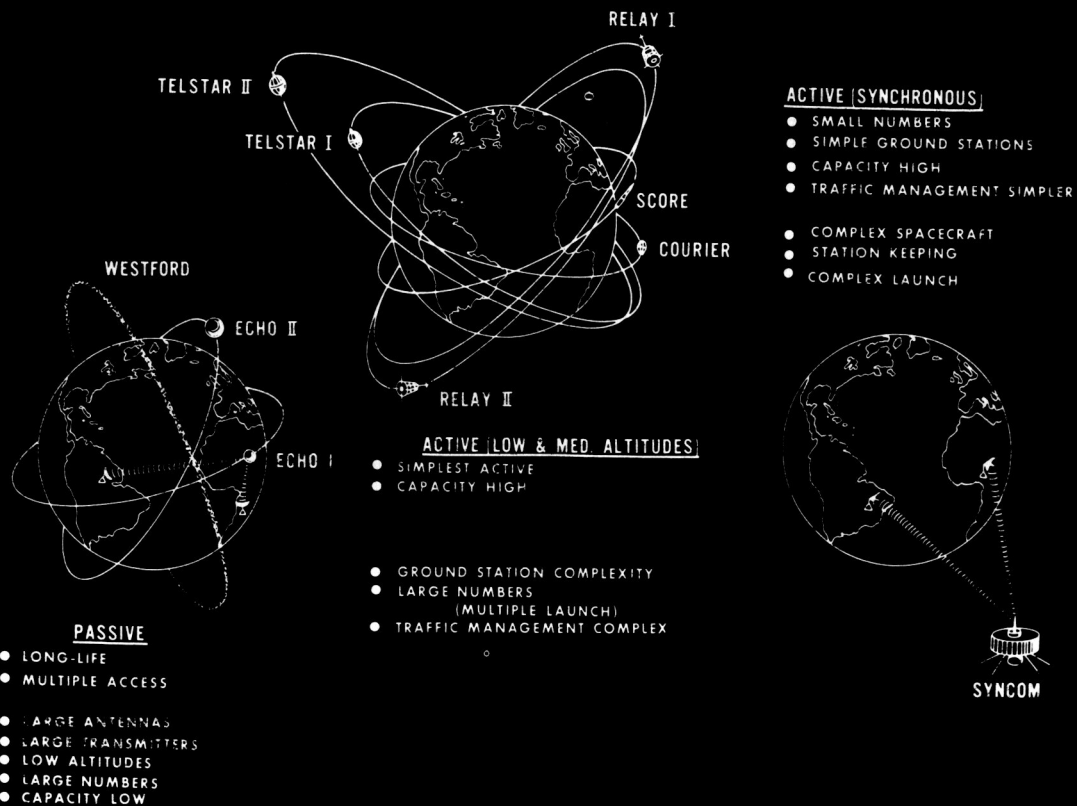
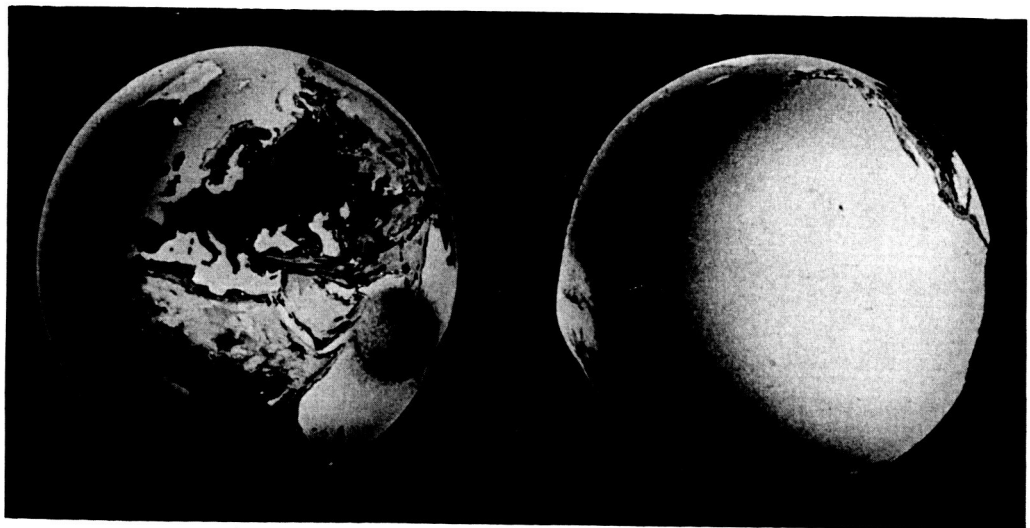


FIGURE 16.

FIGURE 17. GRAVITATIONAL ANOMALIES.



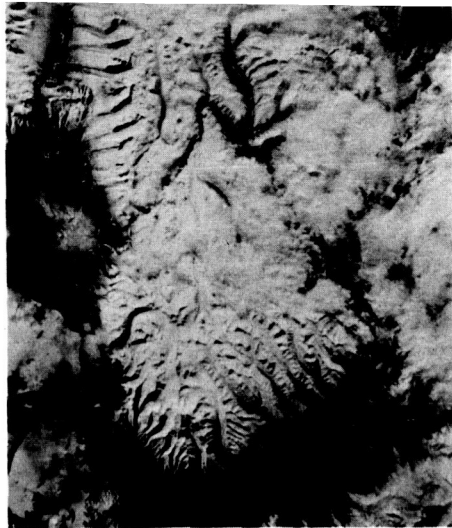


FIGURE 18. PHOTOGRAPH OF THE HIMALAYAS. Taken by Astronaut L. Gordon Cooper, Jr., during orbital flight.

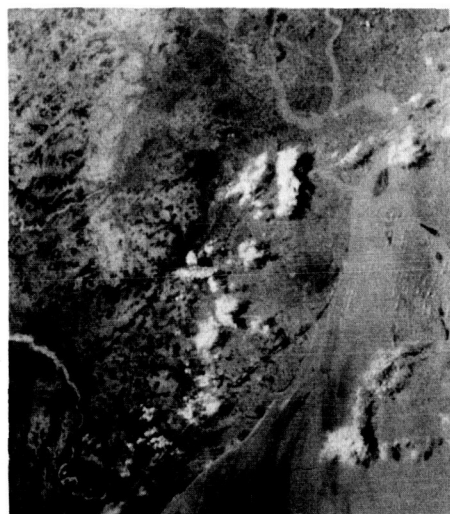
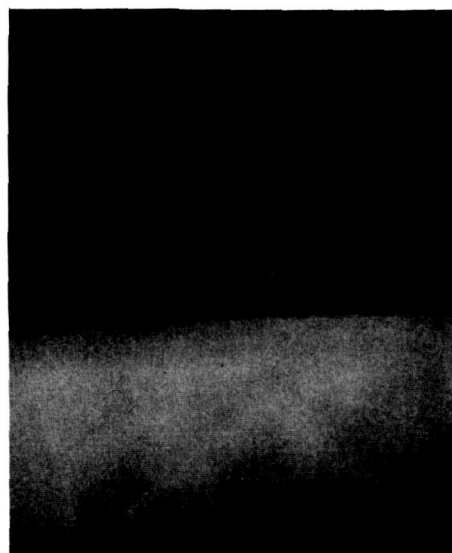


FIGURE 19. PHOTOGRAPH OF CALCUTTA AREA. Taken by Astronaut L. Gordon Cooper, Jr., during orbital flight.

FIGURE 20. "BLUE" EARTH AND GREEN AIRGLOW LAYER. Taken by Astronaut L. Gordon Cooper, Jr., during orbital flight.



been done by unmanned spacecraft. But, however effective these spacecraft may be, they can do no more than man designs into them. Man's priceless ability to cope with the unforeseen must ultimately carry him into space as an explorer. Just now, man is occupied with learning to live and function in space. His main observations are of himself and I will not dwell on these in this paper. In passing, however, I want to show you a few of the sights seen firsthand by only ten living individuals.

Figure 18 shows a segment of the Himalayas as photographed by Gordon Cooper from his spacecraft, Faith 7. An ordinary 70 mm Hasselblad camera was used, so this is an unmagnified representation. The detail of snowy peaks, green valleys, partially frozen lakes, and rivers is striking. Under such viewing conditions, Cooper was able to detect small villages and even individual buildings. In a similar photograph, geologists located a "dome" which may be an excellent place to drill for oil.

Figure 19 shows the Calcutta area, as photographed by Astronaut Cooper. Wandering through the upper center of the picture is the Hoogly River on which lies the city, here obscured by a haze. In the lower right quadrant can be seen the Bay of Bengal and the mouths of the Ganges. Moving clockwise, one notices color variation attributable to the currents near the coastal canal which is clearly seen in the left bottom quadrant. In the far upper left corner is the Damodar River. The full scientific potential of color photography of the earth from satellites has yet to be realized.

Figure 20 is a photograph of night air glow, one of the scientific experiments of the Cooper flight.

The two-man spacecraft Gemini flights will permit a large number of scientific and technological experiments during flights of up to two weeks. In later Gemini flights, the astronauts will be able to emerge from the spacecraft and float free in space. All of these steps lead toward the day when man achieves what appears to be his ultimate destiny in space, the exploration of the moon and planets.

THE MOON AND PLANETS



The exploration of other planets in the solar system has just begun. On December 14, 1962, the second U.S. attempt to send an instrumented spacecraft to another planet culminated with the successful fly-by of Venus by Mariner II.

The fly-by is illustrated in Figure 21. During the 109-day flight to Venus, Mariner II travelled about 35 million miles away from the earth. During the flight, the trajectory was refined so that the spacecraft passed the planet at a distance of about 21,000 miles. At Venus, the Mariner scanned the planet with radiometers and telemetered the data back to earth.

Mariner II provided such information as: there is a solar wind; Venus has no appreciable magnetic field or radiation belt at 20,400 miles; facts which are consistent with the slow rotation of Venus and the theory which holds that planetary magnetic fields are generated by their rotation. There were no large scale breaks in the Venus clouds. The apparent high temperatures of Venus do not come from a hot ionosphere. And the surface is indeed very hot (above 752°F).

On November 28, 1964 Mariner IV was launched towards Mars on a trajectory which will take it past the planet, at a distance of 5000 miles, on July 14, and make measurements of this planet. The spacecraft is shown in Figure 22 against the background of a photograph of the planet. This is a much more difficult mission than the Mariner II flight to Venus. At Mars, the spacecraft will have travelled about 144 million miles from the earth and will have been in transit about 8 months.

As difficult as these missions are, Mars has a singular attraction which cannot be denied. Each Martian summer, there is a wave of visible darkening, much as could be expected from the growth of surface vegetation. In addition, astronomers have detected radiations from Mars indicating the presence of hydrocarbon bonds which might indicate organic substances. If there is extra-terrestrial life,

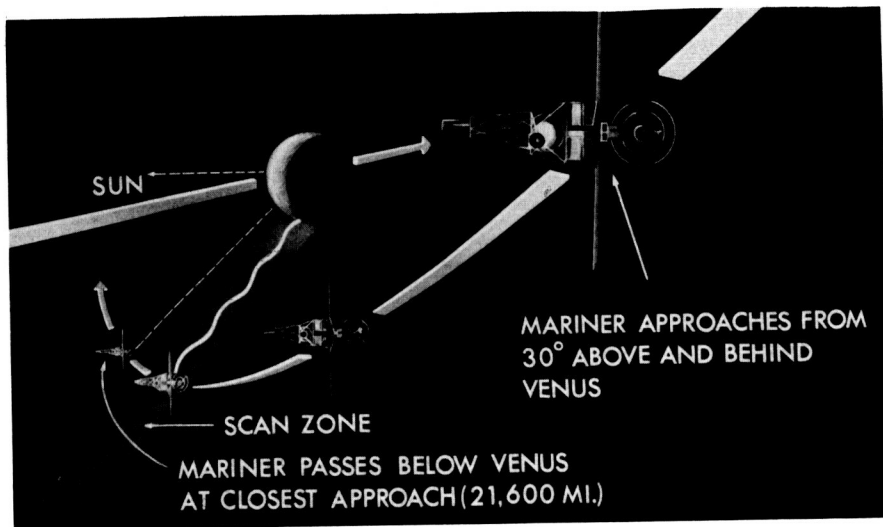


FIGURE 21. MARINER II PASS OF VENUS—AS SEEN FROM EARTH.

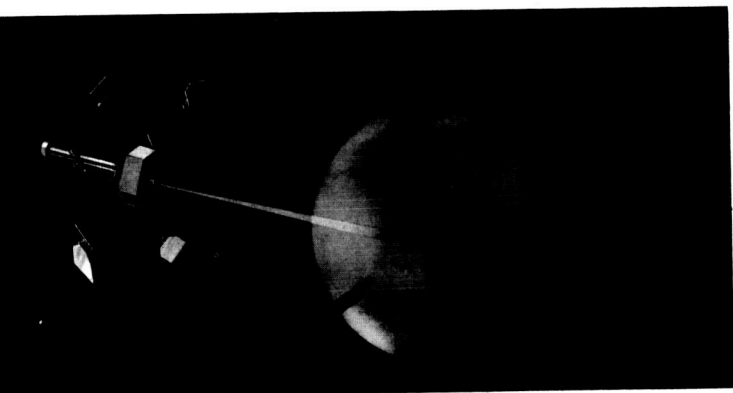


FIGURE 22. MARS ENCOUNTER.

FIGURE 24. SIGNIFICANCE OF HIGH RESOLUTION LUNAR PHOTOGRAPHY.

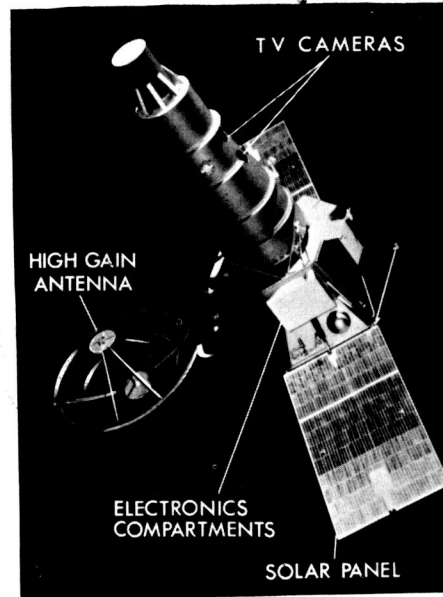
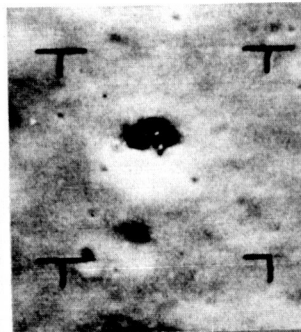


FIGURE 23. RANGER BLOCK III. (Based on Ranger VII Data.) Gross Weight—807 lbs. • Instrument Weight—382 lbs. • Investigations—6 TV cameras • Power From Solar Panels—180 watts • Power Required—117 watts • Stabilization—3 Axis Attitude Control (cold gas) • Design Life—69 hr. transit • Launch Vehicle—Atlas D/Agena B • Trajectory—Lunar Impact • Plan—two flights in 1st quarter 1965.

RANGER VII
PHOTO

GROUND
RESOLUTION
30 FT.



PORTION
OF
BOSTON

GROUND
RESOLUTION
5 FT.



we must find it, identify it, and relate it to our own. The implications are staggering even if such life assumes only the most elemental forms.

Many astronomers have long held that the "vacuum packed" moon may hold on or near its surface the secret to the 4½ billion-year history of the earth-moon system. Being airless, the moon has no wind or rain to weather or erode it. However, it is eroded by the radiations from the sun and outer space, by the continuous bombardment of meteoroids and dust, and by the thermal stresses of the extreme day-to-night temperature range. To what depth, we do not know.

Being closer than the planets, and easier to reach, the moon was selected as the target for man's first extraterrestrial exploration. Before man goes to the moon, however, enough unmanned scientific exploration must be conducted to both insure his safety and to maximize his effectiveness once there. From an operational point of view, there are three prime questions. How rough is the surface? How hard is the surface? Where are the best landing sites?

The United States has a three-pronged program to get these answers. On July 31, 1964, the successful photographic mission of Ranger VII provided 4316 excellent photographs to help astronomers and geologists check their concepts of the lunar surface.¹ Within the next two years, an unmanned Surveyor spacecraft will hopefully land and determine bearing strength. In addition, we are building a lunar orbiter to conduct detailed photographic reconnaissance with millions of times the coverage possible with the Ranger series. By the time man goes, the way should be well charted.

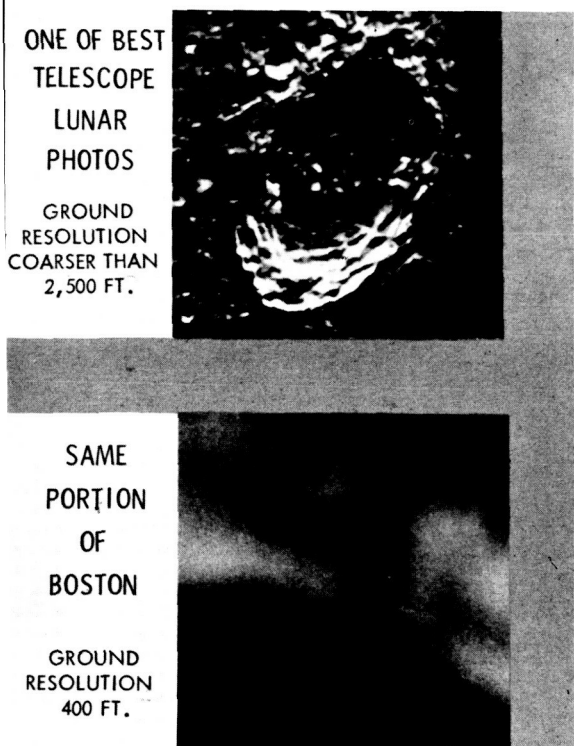
The Ranger spacecraft which made the historic lunar flight is shown in Figure 23. Ranger VII was actually our fifth Ranger flight to the moon, our third impact, and our first total success of the series. Ranger VI flew to within 20 miles of its target, but the cameras failed to operate. Ranger VII flew to within 8 miles of its target and functioned perfectly.

Before the flight of Ranger VII, we could only surmise the nature of the lunar topography. The extent of our ignorance is illustrated in Figure 24. In the upper right is an excellent photograph of the moon taken from earth. The optical resolution is about 2508 feet. Below it is an aerial photograph of the U.S. city of Boston, Massachusetts, at a resolution of 394 feet. Were Boston to be located on the moon, we might notice a small blur but would have no knowledge of what it was. On the lower left is Boston at a resolution of 5 feet. Thanks to Ranger VII, we were able to fill in the upper left with a photograph of the lunar surface showing what may be a partially buried rock about the size of a large building. Mare Nubium is not like Boston!

Let's take a further look at what the moon *is* like. Figure 25 shows a 222 mile square taken from an altitude of 461 miles. This picture closely duplicates the resolution of earth photography, about one half mile. The sharp deep crater is Darney. It is about 10 miles across and one mile deep. The impact area is just south of the small mountain ridge in the upper right. The outline of the next photograph is shown.

Figure 26 shows this next picture taken from an altitude of 228 miles. The picture is 110 miles on a side and craters of about 984 feet are discernible.

¹ On February 20, 1965 Ranger VIII acquired an additional 7,162 photographs of the moon's surface, this time of an area in the Sea of Tranquility. Ranger IX, on March 24, 1965, sent 5,814 pictures of an area at the edge of the Sea of Clouds.



Darney is in the lower left and the small mountain ridge is in the upper right. For the next picture, choose as your reference the pair of craters below the mountain ridge. The impact point is slightly above and to the left of these craters.

Figure 27 shows the next photograph taken from 82 miles. It is 39 miles on a side and 482 feet craters are clearly visible. In addition to the sharp primary craters made by meteoroid impact, large clusters of secondary craters of somewhat softer outline are becoming visible. These are believed to have been created by some of the material splashed out when the crater Tycho was formed. The Ranger impact point was slightly above the regular cluster of six craters to the northwest of the two largest primary craters.

Figure 28 shows this area more clearly.* This picture was taken from 33 miles and is 15 miles on a side. Craters as small as 164 feet are visible. The impact point missed the center of this "battered" area and is above the regular cluster of six.

For Figure 29, Ranger VII was down to 11 miles. The picture is about 5½ miles on a side and craters of about 46 feet are visible. These craters *look* softly rounded because they *are* softly rounded. Occasional clearly-discernible small conical craters attest to the sharpness of the photography and demonstrate that the soft or blurred appearance of the secondary and tertiary craters is their true appearance. In the upper left of the outline of the next frame is an oblong object.

Figure 30 indicates that the oblong object shown

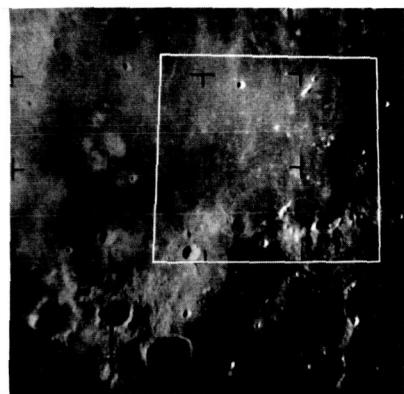


FIGURE 25—LUNAR PHOTOGRAPH TAKEN BY RANGER VII ON JULY 31, 1964—Vertical Altitude —461 miles.

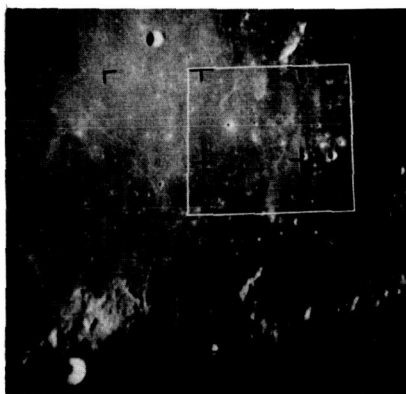


FIGURE 26. LUNAR PHOTOGRAPH TAKEN BY RANGER VII ON JULY 31, 1964—Vertical Altitude —228 miles.

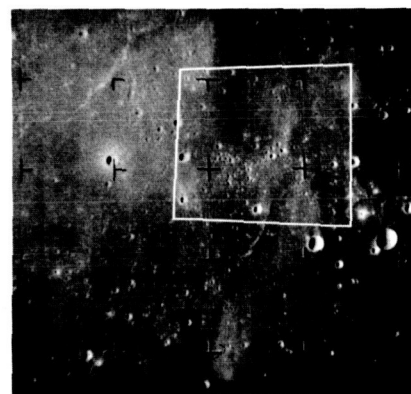


FIGURE 27. LUNAR PHOTOGRAPH TAKEN BY RANGER VII ON JULY 31, 1964—Vertical Altitude —82 miles.

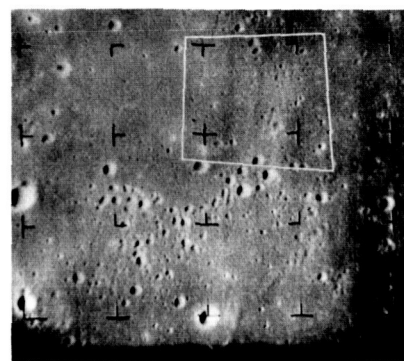


FIGURE 28. LUNAR PHOTOGRAPH TAKEN BY RANGER VII ON JULY 31, 1964—Vertical Altitude —33 miles.

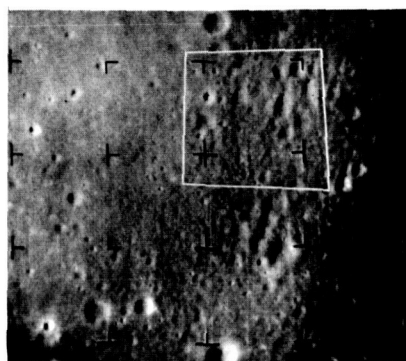


FIGURE 29. LUNAR PHOTOGRAPH TAKEN BY RANGER VII ON JULY 31, 1964—Vertical Altitude —11 miles.



FIGURE 30. LUNAR PHOTOGRAPH TAKEN BY RANGER VII ON JULY 31, 1964—Vertical Altitude —3½ miles.

in Figure 29, is a half buried rock about 290 feet in length. This is the last photograph taken with the A Camera, which had a 25 mm f/1 lens. Transmission of the picture was terminated by impact as shown by the loss of signal at the right of the picture. This picture was taken at $3\frac{1}{2}$ miles and is $1\frac{1}{4}$ miles on a side. Craters as small as 29 feet in diameter and 9.8 feet deep are visible. The impact point is again to the upper right of center.

The highest resolution pictures we obtained are presented in Figure 31. The full frame was taken at an altitude of 2976 feet and is 98 feet on a side. The partial frame was taken at 990 feet but with a

shorter focal length so that, although the frame is 165 feet on the full side, it has the same resolution at the full frame. The speckled pattern is caused by receiver noise after Ranger impact. These areas are about the size of a small suburban lot and are much smaller than this room. The resolution was about one foot and craters of about $1\frac{1}{2}$ feet diameter are visible—about the size of a dishpan, and about as deep.

A final still photograph of the moon is shown in Figure 32. This picture is the same as Figure 30 except that a number of higher resolution pictures taken with another camera are superimposed near the impact point. These superimposed pictures retain the high resolution detail, and, if you look closely, you can see the detail the larger picture failed to bring out. The final tiny frame of Figure 31 appears to the upper left of the high resolution group. A major conclusion which can be drawn is that the small area in the final high resolution picture is probably quite typical of large areas of this mare, newly named Mare Cognitum in honor of the flight.

We sent Rangers VI and VII to the maria because they looked like the smoothest and most level areas on an otherwise very rugged moon. We did not find them entirely smooth and level, but rather peppered with secondary and tertiary craters of all sizes and with an undulating contour. However, there is a remarkable absence of rocks and boulders, and of cracks and fissures, which indicates that debris from crater splashes has either been eroded or buried. If one avoids the larger secondary craters, and selects a spot such as the Ranger VII impact point, it is clear that the surface is smooth enough and level enough to land on with the manned spacecraft which the United States is building. The question of surface hardness or bearing strength is still being argued and will not be answered until the Surveyor, or a Soviet equivalent, makes the first unmanned soft landing on the moon.

Meanwhile, our plans to land men on the moon move ahead. As shown in Figure 33, the United States is building three giant rockets as part of the Apollo program. The Saturn I, capable of orbiting 22,000 lbs., is already flying. The Saturn IB and the Saturn V are not too far behind. The latter, which will be used for the lunar mission, can orbit over 220,000 lbs., and can launch to the moon nearly 99,000 lbs. It is as tall as a 30-story building.

Sometime, hopefully about the end of this decade, three men will undertake the mission shown in Fig-

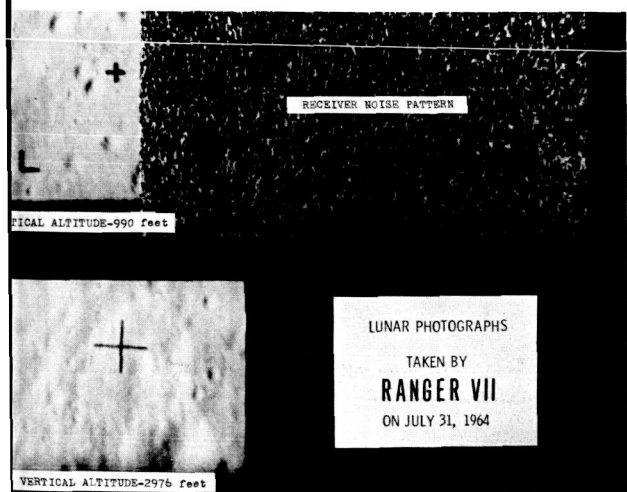
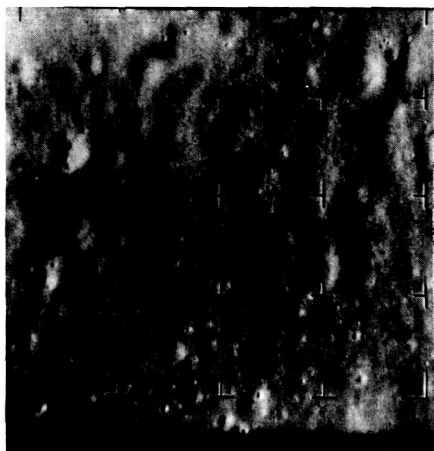


FIGURE 31.

FIGURE 32. LUNAR PHOTOGRAPH TAKEN ON JULY 31, 1964 BY RANGER VII—Mosaic composed of last photograph from the F-a camera with last five partial scan camera photographs superimposed.



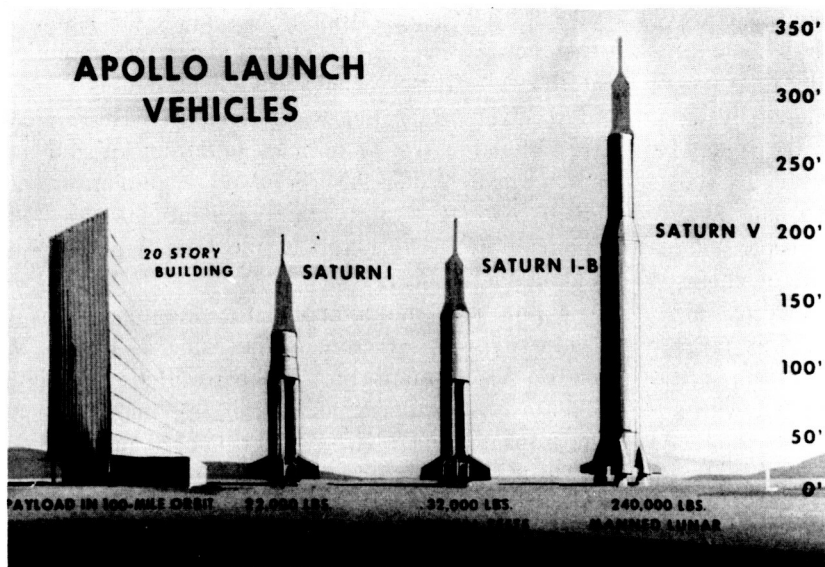


FIGURE 33.

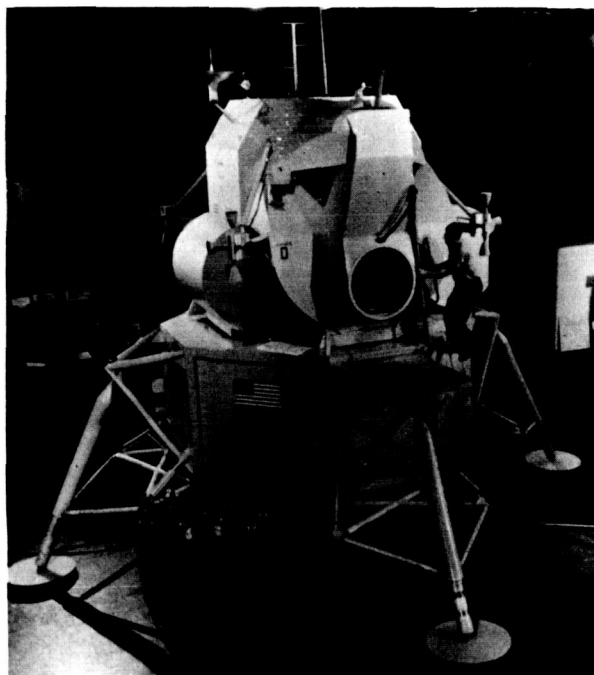


FIGURE 35. THE APOLLO TM-1 MOCK-UP.

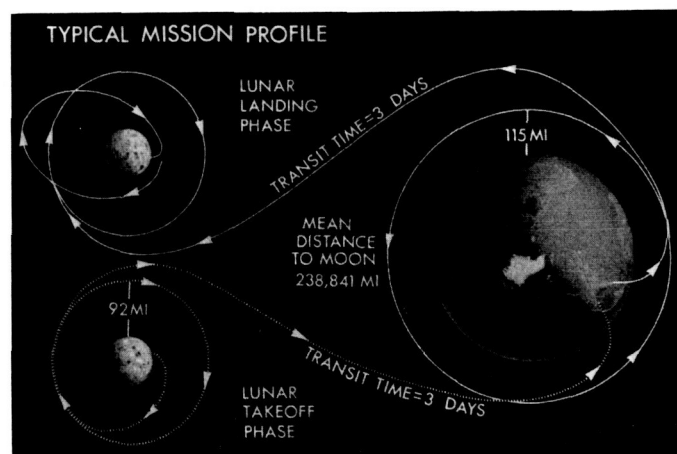


FIGURE 34. APOLLO MISSION PROFILE—LUNAR ORBITAL RENDEZVOUS MODE.

ure 34. A three-day flight will take them to the moon where they will go into orbit. A special landing craft carrying two of the three men will detach itself from the main spacecraft and descend to the lunar surface. After a relatively short period of surface exploration, these men will take off and rendezvous with the basic Apollo spacecraft. They will then transfer into the reentry vehicle for the 3-day return flight. Another chapter in history will be written.

The last figure shows a full scale mock-up of the lunar landing spacecraft (Figure 35). The workman gives an idea of the size. However fantastic the concept of this craft sitting on the lunar surface might have seemed a few short years ago, most of us should live to see it happen.